

Full-scale Evaluation in a Fatigue Track of a Base Course Treated with Geopolymers

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Abstract

Usually, optimal percentages of additives used to improve the characteristics of soils, are determined by laboratory tests of different complexity. Then, these optimal combinations are used directly in the pavement structures, without analysis of time or scale differences between laboratory and field conditions. This paper presents the results of a full-scale accelerated pavement test on a base course that has been improved by using fly ash and an alkali activator. Initially, the main characteristics of the testing equipment are presented. The optimal amount of the different components was previously obtained by laboratory tests. The components were mixed, the material was extended and compacted in layers and a curing time was permitted. After that, a wheel loaded with a vertical hydraulic actuator, simulating a rear half-axis of a truck, passed on the top layer repeated times. During the test, vertical deformations of the surface were measured in several points along the track. Results after around 10000 loading repetitions were compared against simultaneous measurements on a non-treated material subjected to identical loading application, showing the advantages of the alkali activation in reducing deformability of base courses and the effect of variable natural wheatear conditions on both type of pavement structures.

Keywords: alkali activation, fatigue test, rutting

1 Introduction

Tertiary roads in remote areas need low-cost construction materials, which usually should be obtained locally. This restriction sometimes imposes the condition of using materials that do not meet technical specifications for such use. In the particular case of granular materials, mechanical or chemical stabilization are alternatives to improve their quality. The main purposes of soil stabilization are to: modify the soil, expedite construction and improve the strength and durability of the soil (Das, 1995). In the chemical stabilization, the soil is mixed with other substances that react with the minerals or water present in the soil mass, producing a decrease in void ratio, reduction of water content, joining of fissures or cementation of particles. Cement and lime are commonly used as chemical stabilizers. However, production of these materials involves consumption of natural resources and it is recognized as an activity of high environmental impact (Chen, Hong, & Xu, 2015).

Coal burning fly ash is an industrial waste of rising interest as alternative component in production of materials for the civil and infrastructure construction industry. For example, the use of geopolymers resulting from the alkaline activation of fly ash has been used for different application such as to replace the ordinary Portland cement concrete (Kupwade-Patil & Allouche, 2013). While the chemical reactions are described in detail by Duxson *et al.* (2007), an explanation of the use of geopolymers for soil improvement can be found in Rios *et al.* (2015).

The mechanical characterization in laboratory of soils stabilized by alkaline-activated fly ash is necessary to obtain the optimum percentages of activators and fly ash to be used in field. However, the actual performance of the stabilized soil should be tested in full scale by either in a short section of a road in service or in a prototype built in a fatigue track with simulated traffic. Full-scale testing reduces the necessity of extrapolation in scale, time or environmental condition (Powell, 2012). Apart of the scale similarities, the advantages of the full-scale test include the application of a loading regime comparable with the future traffic and exposition of the structure to the real weather conditions. The economic benefits of accelerated pavement testing (APT) in design are discussed by du Plessis *et al.* (2012). There are many works on APT on pavement roads, but few reports of using this facility to study unpaved roads as for example Yang *et al.* (2012). This paper shows the results of an unpaved base course treated with activated fly ash subjected to moving loading in a fatigue track. Variations of climatic conditions during curing and testing periods were measured by using a portable climatic station. The length of the track allowed the simultaneous test of a section of non-treated material under identical loading and environmental conditions, making possible direct comparisons between results.

2 Equipment and Experimental Procedure

2.1 Description of the Fatigue Track

The full-scale accelerated fatigue track is located in the Nueva Granada Military University at Cajicá (Colombia). The equipment is composed by three main parts: two boxes of concrete (each one 3m wide, 12m length and 1.5m depth) to contain the pavement structures to be tested; a steel structure to support the mechanical components and provide the reaction to vertical loading; and the mechanic/hydraulic components that generate the moving load (Vargas-Fonseca, Reyes-Ortiz, & Camacho-Tauta, 2014). Figure 1 shows a picture of the fatigue track anchored over one of the concrete boxes, which is filled with the soil structure. The deep of the concrete box allows a prototype with the complete layers of a conventional pavement structure from subgrade to surface course. The maximum speed of the wheel is 18 km/hour due to the length of the track in combination with a high-precision controlled servomotor. The second box can be used to construct a second pavement structure, while the test is running on the first box.



Figure 1: Fatigue track for evaluation of pavement structures

2.2 Materials and Preparation

Figure 2 presents the grading curve of the base course before treatment. The laboratory compaction test was performed using to the modified method according to the standard D1557-12e1 (ASTM International, 2012), giving maximum dry unit weight, $\gamma_{dmax} = 20.0 \text{ kN/m}^3$ and optimum water content, $\omega_{opt} = 7.7\%$. The specific gravity, $G_s = 2.76$ and the fine content was non plastic. Fly ash was type F obtained from a thermoelectric power plant. The chemical composition is presented in Table 1 in which the main components are SiO_2 and Al_2O_3 . Grain size distribution was measured by laser diffraction as presented in Figure 3a with a maximum size of $100 \mu\text{m}$. X-ray diffraction analysis (Figure 3b) exhibits a main composition of quartz, mullite, hematite and low percentage of calcium oxide. A mixture of sodium hydroxide and sodium silicate was used as alkaline activator. Sodium hydroxide is commercially delivered in 20kg-bags of small white pellets and sodium silicate in a form of aqueous colorless solution.

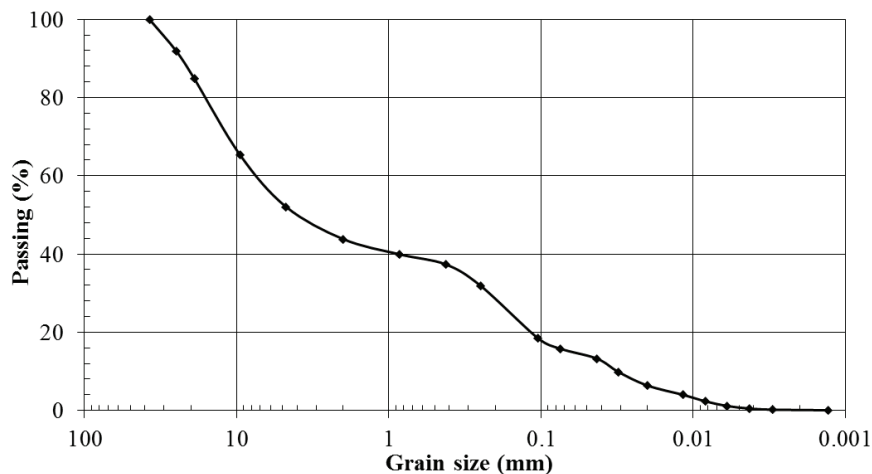


Figure 2: Grading curve of the soil

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	MnO	P_2O_5	TiO_2	I.L. ^(a)	I.R. ^(b)
51.78	27.80	6.18	4.59	1.52	0.71	0.59	2.51	0.06	0.62	1.35	2.23	0.32
(a) Ignition loss			(b) Insoluble residue									

Table 1: Chemical composition of fly ash

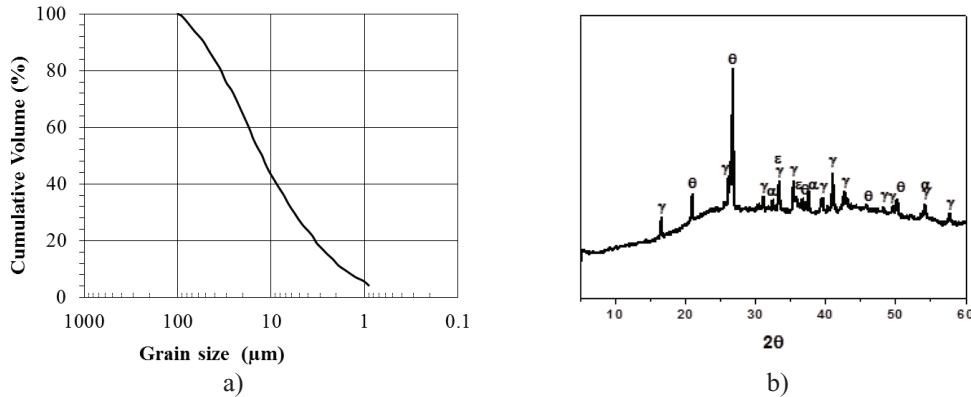


Figure 3: Characterization of fly ash: a) grading curve; b) X-ray diffraction test (Θ:quartz, γ: mullite, ε: hematite, α: calcium oxide)

The optimum percentages of the mixture were obtained in a previous laboratory programme by Rios *et al.* (2016) who included the physical characterization of the granular material and unconfined compression tests with loading-unloading-reloading cycles. Different proportions of fly ash and the two activators (sodium silicate and sodium hydroxide) were tested. Table 2 shows the recommended proportions of the components in weight per compacted cubic meter in the mixture. Soil and fly ash were strongly mixed using a retro excavator until obtain a uniform mixture. Apart, sodium silicate and sodium hydroxide were mixed with water. This solution generates an exothermic reaction, which makes necessary to wait a day to mix it with the fly ash - soil combination.

Material	Weight (%)	Weight (kN)
Soil	82	18.38
Fly ash	10	1.83
Sodium silicate	4	0.76
Sodium hydroxide	1	0.18
Water	3	0.58
Total	100	21.73

Table 2: Proportions of components per compacted cubic meter

The concrete box was filled with non-treated soil in compacted layers of 30cm using a 2 Ton-vibrocompactor. The last 30 cm were compacted in different way: half of the track (6m) was filled with non-treated soil and the second half (6m) was filled with treated soil. Both sections were compacted in three layers of 10cm. Figure 4 shows the sequence of compaction of the first sub layer of the base course. During this step, control of compaction were carried out and compared against the laboratory recommended values, for the non-treated as well as the treated material. The density in field was measured by using the standard D4914-08 (ASTM International, 2008). Results of the compaction control in different sides and layers on original and improved soil are presented in Table 3 and Table 4, respectively. Minimum degree of compaction was over 95%. Compaction of improved soil was greater than 100% in all the cases.

After compaction, it was permitted a curing period during 20 days. The surface was covered with plastic in order to reduce its exposition to rain, but allowing approximately 30 cm between plastic and soil to provide ventilation. Weather conditions did not have extreme variation: Ambient temperature varied between 8.4°C and 20.9°C with an average of 14.2°C. The rain during the curing period reached a maximum of 2mm per day and 14.1 mm accumulated in 20 days. Relative humidity oscillated between 54% and 97%. Finally, solar radiation ranged in 500W/m² with an hourly maximum of 100 W/m².



Figure 4: Compaction of the top layers: a) extent; b) compaction; c) after compaction

Description	Units	Layer 1		Layer 2		Layer 3	
		Left	Right	Left	Right	Left	Right
Water content	%	6.8	6.3	6.9	7.1	7.7	7.2
Dry unit weight	kN/m ³	20.0	19.9	19.7	19.7	20.4	19.2
Degree of compaction	%	100.0	99.5	98.4	98.6	102	95.4

Table 3: Results of field density test in the untreated soil

Description	Units	Layer 1		Layer 2		Layer 3	
		Left	Right	Left	Right	Left	Right
Water content	%	12.2	13.6	16.0	8.9	11.2	10.0
Dry unit weight	kN/m ³	23.1	21.6	19.6	20.9	20.9	21.2
Degree of compaction	%	120.9	113.3	103.1	109.9	110.0	111.1

Table 4: Results of field density test in the soil improved with activated fly ash

2.3 Accelerated Fatigue Tests

Figure 5 presents a schematic view of the track indicating the locations of points A, B, C and D where vertical measurements were taken. The points H and E marks home and end positions of the moving load. The average speed was adjusted to 5 km/hour with a constant total vertical force of 40kN applied by the two wheels over an approximated contact area of 0.18m by 0.32m each. The equipment is not covered with a ceiling and therefore weather conditions affect the soil structure. This fact is advantageous when the user needs to test under actual climate variations. However, electro mechanic components of the apparatus are not totally protected against rain. For this reason, when extreme rain appeared, the test was paused and essential parts of the equipment were protected with plastic.

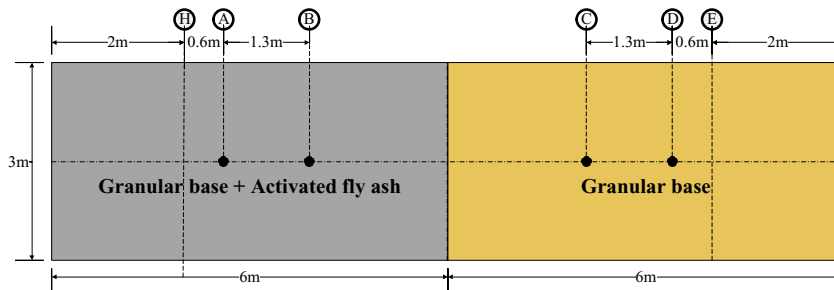


Figure 5: Schematic top view of track tests with location of measurement points

3 Results and Discussion

During the period in which the test was running, different rain conditions were present as can be seen in Figure 6. This situation affected the duration of the test, because during rainy days the test had to be stopped. Once rain decreased, the test was reinitiated but water affected the behavior of both soils. Finally, a total of 10600 cycles were applied in a total of eight days. Table 5 presents the vertical deformations measured in points A, B, C and D after each day. Figure 7 illustrates de rutting after the first day of testing. During the first two days in which the rain was not present, the accumulated vertical deformation in the improved soil was lower than in the non-treated soil. The test was restarted after nine days of intense raining. This weather conditions affected the performance of both soils, but this negative effect was more pronounced in the treated soil. As the climatic condition became better, the treated soil reduced its rate of deformation until be almost equal to the cumulate deformation of untreated soil. In order to analyze the experimental results, the test was divided into three stages according to meteorological conditions, which had strong influence on results (Figure 8).

The first stage from 0 to 4600 cycles was performed without significantly rain. In this first stage, the rate of deformation in the treated soil (1.7mm/1000cycles) was slightly lower than in the non-treated soil (1.8mm/1000 cycles).

The second stage from 4600 to 7800 cycles ran after nine days of intense rain. Soil properties of both materials decreased and, consequently vertical deformations increased significantly. The effect of raining had an immediate consequence in both soils. However, the first cycles of this stage produced 20 mm more deformation in the treated soil than in the non-treated soil. This difference was nearly constant along the stage. The gradient of deformation was approximately equal for both soils, being 22mm/1000 cycles and 23 mm/1000 cycles, respectively.

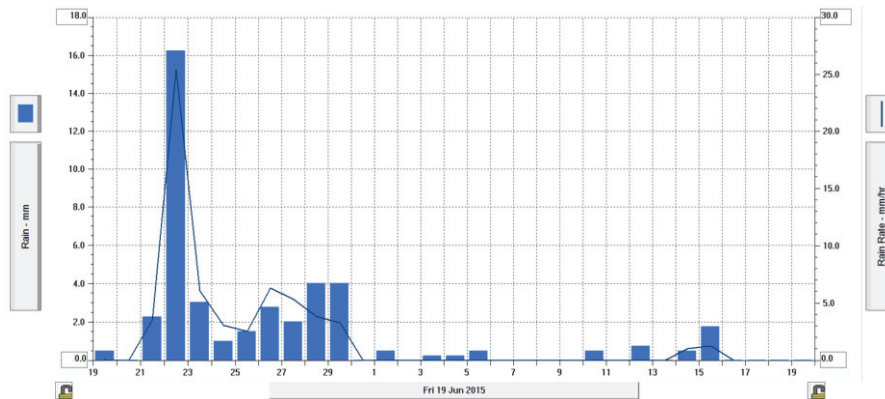


Figure 6: Variation of precipitation during the testing period

Day	Date	Cycles	Cumulate cycles	A	B	C	D
1	2015/06/19	1400	1400	3	3	5	5
2	2015/06/21	3200	4600	8	10	10	11
3	2015/07/01	200	4800	35	39	12	23
4	2015/07/03	500	5300	46	54	23	29
5	2015/07/06	1300	6600	75	90	53	58
6	2015/07/07	1200	7800	95	110	92	82
7	2015/07/08	1600	9400	105	115	105	95
8	2015/07/09	1200	10600	115	116	108	96

Table 5: Vertical deformation (mm) in different points after cycles of accelerated fatigue test



Figure 7: Vertical deformation after 1400 cycles: a) non-treated soil; b) treated soil

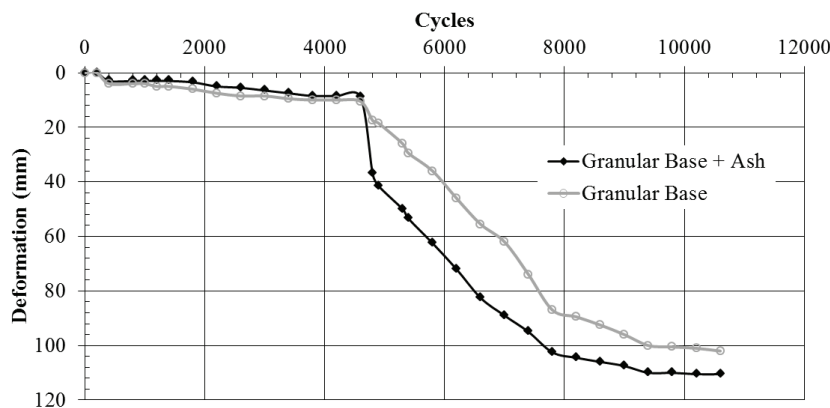


Figure 8: Average vertical deformation

The last stage from 7800 to 10600 cycles was carried out during sunny days that reduced water content and increase again the soil stiffness. As the moisture was decreasing, the stiffness increased in both soils. It is clear a gradual trend in the slope from 8.8mm/1000 cycles to 1.6mm/1000 cycles in the non-treated soil and from 4.5mm/1000 cycles to 0.5mm/1000 cycles in the treated soil.

The gradient of deformation in the three stages was always lower in the treated soil. The total deformation in this case exceeded the total deformation of the non-treated soil only due to the immediate effect after the starting of raining. Fly ash increases the fines content of the soil and hence it would be more vulnerable to changes in moisture conditions. The curing period allowed in this test might not have been sufficient to reach permanent positive changes in the soil properties before fatigue tests.

4 Conclusions

A full-scale experimental investigation using an accelerated pavement testing facility was used to simultaneously test two types of unpaved road structures: a base course using granular material and a second base using the same soil but mixed with alkaline-activated fly ash. Thus, the test was carried out under identical loading and climatic conditions.

Raining during the period of testing affected both soil structures, especially the treated soil just immediately after the rain. Despite this punctual deformation, the average result in terms of rate of deformations was comparatively favorable for the treated soil.

The test was executed under natural climatic conditions and no asphaltic or hydraulic concrete protected the granular base. Moreover, no drainage conditions were provided in this case because the

idea was to simulate a tertiary road. It is expectable a better performance of the alkaline-activated fly ash as stabilizer in roads with improved conditions of superficial treatment and drainage.

Acknowledgments

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